OVERVIEW AND RESULTS OF FIRE PSA STUDY FOR NOVOVORONEZH NPP UNIT 5

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INTRODUCTION

A fire risk analysis has been initiated for the Unit 5 of Novovoronezh Nuclear Power Plant (NVNPP-5), the first Russian VVER-1000 reactor. The analysis is carried out within the framework of the joint Swiss-Russian Probabilistic Safety Assessment (PSA) project (SWISRUS). The main objective of the SWISRUS* project is to assist in the training of the technical staff of the Scientific and Engineering Center for Nuclear and Radiation Safety (SEC NRS), which is the technical support organization of the Federal Nuclear and Radiation Safety Authority of Russia (i.e., Russian Federation Gosatomnadzor [GAN]), for performance and application of PSAs in safety evaluation of Russian nuclear power plants [1]. The PSA project is carried out under the technical direction of the Swiss Federal Nuclear Safety Inspectorate (HSK). Energy Research, Inc. (ERI) assists HSK in project management, training, technical support and review. Technical work is performed by members of SEC NRS and the Novovoronezh plant.

The first phase of SWISRUS project, Level 1 PSA for internal initiators of Novovoronezh NPP Unit 5, started in November 1994, and was completed in June 1999 [2]. The second phase of the SWISRUS project comprising external events and level-2 PSA tasks is scheduled to be completed by early 2001. The fire risk analysis (fire PSA) discussed in this paper is part of this second phase.

This paper presents a brief overview of the methodology and assumptions used in the fire PSA study and discusses the main quantitative results and dominant contributors to the total CDF associated with internal fires for Unit 5 of Novovoronezh NPP.

1. MAIN FEATURES OF NVNPP-5

The Novovoronezh NPP Unit 5, a nuclear power plant rated at 1000 MW(e), is a water cooled, water moderated VVER Pressurized Water Reactor (PWR) that started commercial operation on May 30, 1980. It is the first VVER-1000 type nuclear power plant that was designed and constructed in the former Soviet Union

* The SWISRUS project is the result of cooperation between the Swiss and the Russian Nuclear Regulatory Authorities, and is sponsored by the Swiss Government, Agency for Development and Cooperation, Division of Cooperation with Eastern Europe and the Commonwealth of Independent States (DEZA/AZO).

The NVNPP-5 reactor coolant system includes the reactor, a pressurizer, and four coolant loops, each connected to a horizontal steam generator and a main reactor coolant pump. Each coolant loop also includes two valves for isolating the steam generator from the reactor vessel. The radioactive coolant circuit equipment are enclosed in a concrete containment building which is designed to withstand an internal pressure of 0.45 MPa.

The secondary circuit consists of four steam generators, two steam-driven main feedwater pumps, two turbine-generators and related appurtenances. There are emergency feedwater pumps that are located in the basement of the turbine building. The secondary side is also equipped with Fast Acting Isolation Valves (FAIV) on the main steam lines.

The main elements of plant layout include the containment, the auxiliary building, the turbine building, the diesel generator building and intake structures. The auxiliary building can be envisioned in two parts: the radioactive area and electrical and control area. The radioactive area houses pumps, piping, valves, and supply tanks. The electrical and control areas are located between the main part of the auxiliary building and turbine hall. It houses electrical power and control buses, batteries, the cable chases and cable spreading rooms. The turbine building houses the two turbines and related pumps and equipment. The fire protection related equipment control panels are located in a compartment that is considered as part of the turbine building.

The radioactive area of the auxiliary building consists of several compartments and corridors that are in the majority of cases connected to each other via openings in the walls. Redundant pumps of the same system are often installed inside the same compartment. To control contamination, the floor of the majority of the areas is covered with a special resinous material. The material is suspected to be somewhat combustible and to emanate toxic fumes upon combustion.

The Main Control Room (MCR) is a large area where the main control panel is located. There are two adjacent rooms that are generally open to the MCR. These rooms house the relays and the main computer. The fire suppression system of the control room includes CO_2 fire extinguishers, and two hose reels installed on the walls immediately outside the control room doors. The main access to the control room is from the turbine building.

An important fire related feature of NVNPP-5 is the Alternate or Reserve Control Room (RCR), which was incorporated into the original design of the plant. Redundant trains of safety related equipment can be controlled from this room. All the control keys in MCR and RCR are operable at the same time. However, the control circuit design of certain control valves includes a feature that allows for the connection to the MCR to be overridden by a switch in the RCR, making the RCR as the main control point of the affected equipment.

2 OVERVIEW OF FIRE PSA METHODOLOGY

The methodology used in the fire PSA is based on References [3], [4] and [5]. Fire hazard analysis, as it is defined in Reference [5] has not been conducted for NVNPP-5. Therefore, when starting the fire PSA, little or no information was available regarding fire zones, fire areas, and routing of the cables. The fire PSA team had to develop an approach for defining fire areas and fire zones and for identifying cable routing information. Based on the information collected, two graduating levels of analysis were applied in the study: screening and detail analysis. Only those compartments were analyzed in detail that were suspected to be important to fire risk.

2.1 Plant Information Collection

The scope of information required for the fire PSA was identified and the process of information collection was established. Main items of information were as follows:

- Layout drawings of plant buildings and compartments;

- Plant system descriptions, including fire protection systems;
- Plant procedures for normal and emergency operation;
- Fire fighting procedures;
- Construction notes on cable routing;
- Electrical circuit schematics;
- Plant operational experience and statistics on fire-related events, etc.

The work on plant information collection was often conducted in parallel with other PSA tasks.

2.2 Plant Walkdowns

Several plant walkdowns were performed at different stages of the analysis. The initial walkdown was aimed at a general familiarization with plant layout and design features. From the information obtained in the first walkdown, fire zone boundaries were defined. In the second walkdown fire zone definitions and mapping of PSA components to plant areas were verified. Sources of fire hazards, characteristics of the fire protection systems and integrity of fire boundaries were also studied. Standardized set of forms was used to record the information obtained in this second walkdown.

Additional verification walkdowns were later performed in support of the detailed analysis for selected plant areas. The purpose of these walkdowns was collection of specific information required for fire propagation analysis, fire phenomena modeling, fire suppression modeling, control circuit analysis, etc. Some of the major walkdown findings that were subsequently taken into account in the analysis are as follows:

- It was discovered that the boundaries of some of the fire zones were compromised by openings.
- Some deviations from the original compartment layout documentation and connections not included in the original design documentation were discovered. For example, the fire zone where make-up pumps, heat exchangers and oil tanks are located has a series of ventilation openings in the walls. These openings are equipped with dampers that are kept closed by a counter weight. In case of a fire, the dampers could act as a pathway for the propagation of fire hot gases and smoke.

2.3 Fire Zone Definition

Criteria for dividing the plant into fire zones had to be established first. A coding scheme for identifying the fire zones was developed. The fire zone identification process included three steps:

1) Division of the plant into major buildings and areas;
2) Definition of fire zones within each building or area based on drawings and documents available;
3) Performing plant walkdowns to validate fire zone boundaries defined in the previous two steps.

The entire plant was divided into fire zones and their boundaries were indicated on plant layout drawings. In total, 500 fire zones were identified.

2.4 Initiating Events Caused by a Fire and Compilation of PSA Components List

The initiating events (IEs) considered in the internal events PSA were reviewed. Every item from the complete set of internal initiating events from Reference [2] was evaluated in order to see which initiating event may occur as a result of equipment failures caused by a fire. In this analysis, all possible scenarios in terms of equipment failures caused by a fire leading to an initiating event were identified. For example:

The initiating event "Closure of turbine stop valves on two turbines" may occur from a fire simultaneously affecting the control cables associated with the two stop valves.

"Rupture of steam pipelines outside containment" is not possible to occur from a fire. However, all valves situated on these lines were examined to make sure that there are no valves from this line into low pressure areas of the systems, inadvertent opening of which may simulate the effects of a steam pipe rupture.

Similar initiating events were grouped together according to similarities in plant response. Within each group, the most severe initiating event was selected as the representative of the group, and event trees were selected for modeling each group.

In order to reduce the number of initiating event groups to a manageable size and limit the cable routing information collection effort, two default initiating events were defined. The default initiating events were assigned to those fire scenarios, for which a detailed analysis of possible initiating events was not deemed necessary:

a) The initiating event "Feedwater Pumps Trip" (identified with the designator “FWPT”) was assigned to those fire scenarios that their plant impact had less severe consequences than feedwater pump trip. This initiating event group was used as a “default” for those scenarios where at least one safety related component related to the feedwater system could be affected. That is, for any fire in an area where there is at least one identifiable safety related component or cable, the “default” initiating event was assumed to occur as a minimum. With this assumption there was no need to obtain information on cable routing of all equipment associated with feedwater system operation as the initiating events were covered under FWPT. It should be noted that the contribution of FWPT to overall core damage frequency in internal PSA model was relatively small and was mainly driven by the initiating event frequency.

b) "Administrative Shutdown" (identified with the designator "ADSH") was the second default initiating event that was assigned to those fire scenarios for which no safety-related components/cables could be identified. With this assumption there was no need to learn about how any of the initiating events identified by ADSH may occur. This default initiating event provided the possibility to avoid excessive conservatism resulting from the use of previous default initiating event.

Fault trees were developed to identify the possible ways that a fire could lead to specific initiating events. This led to the identification of additional equipment not previously modeled in the internal events PSA (for example, a fire-induced interfacing LOCA caused by spurious multiple opening of certain MOVs.)

The event trees from the internal events PSA model [2] associated with initiating event groups were used for constructing the plant impact portion of the fire risk model. Several new event trees for those initiating event groups that were not addressed in the internal events PSA model had to be developed.

Event trees associated with the initiating events caused by a fire and associated system fault trees from the internal events PSA were reviewed and components susceptible to damage from a fire were identified and tabulated as PSA components. Additional components were identified as part of the initiating event analysis effort and a list of key instrumentation circuits was added to the PSA component list.

2.5 Cable Routing Information

Prior to this fire PSA there were no suitable documents or computerized databases that would provide a catalog of cable and equipment locations. Because of this shortcoming, a major effort was initiated to create such information for those cables and components that were of interest to the fire PSA (i.e., PSA components).

Special assumptions had to be made to limit the scope of cable routing effort without compromising the validity of the results of the fire risk analysis. This was partly achieved by the defining two default initiating events discussed above.

All the information on cable and equipment locations in plant compartments, as well as compartments included in fire zones and connections among them was incorporated into one database. The database contains 21’000 records of cable location information and 3’000 records of component locations. Computer programs using Visual Basic and Microsoft ACCESS were developed to automate the identification process of fire propagation zones and the cables located in those combinations of fire zones. The database allowed to establish the contents of a compartment in terms of components and cables, and to identify, if needed, the compartments where the cables of a specific component is routed through. The flow chart presented in Figure 1 demonstrates some of the characteristics of the database.

2.6 Fire Frequency Evaluation

Fire initiation frequencies were established for component types using generic and plant specific data. The Bayesian updating approach was used for this purpose. The prior distributions were based on the generic data obtained from fire events at Novovoronezh NPP Units 1-4 and Kalinin NPP. The generic distributions were then updated using data from Novovoronezh NPP Unit 5. The fire occurrence frequencies for components are presented in Table 1.

The frequency of fires from transient combustibles was estimated as the total frequency of such fires for the entire plant and then partitioned among fire zones by taking into account the floor area of the fire zones and frequency of personnel visits. The mean value of total frequency of transient combustible fires was estimated as 1.5E-02 per reactor*year. The same partitioning approach was used for the assessment of fire occurrence frequency from metal works (mean

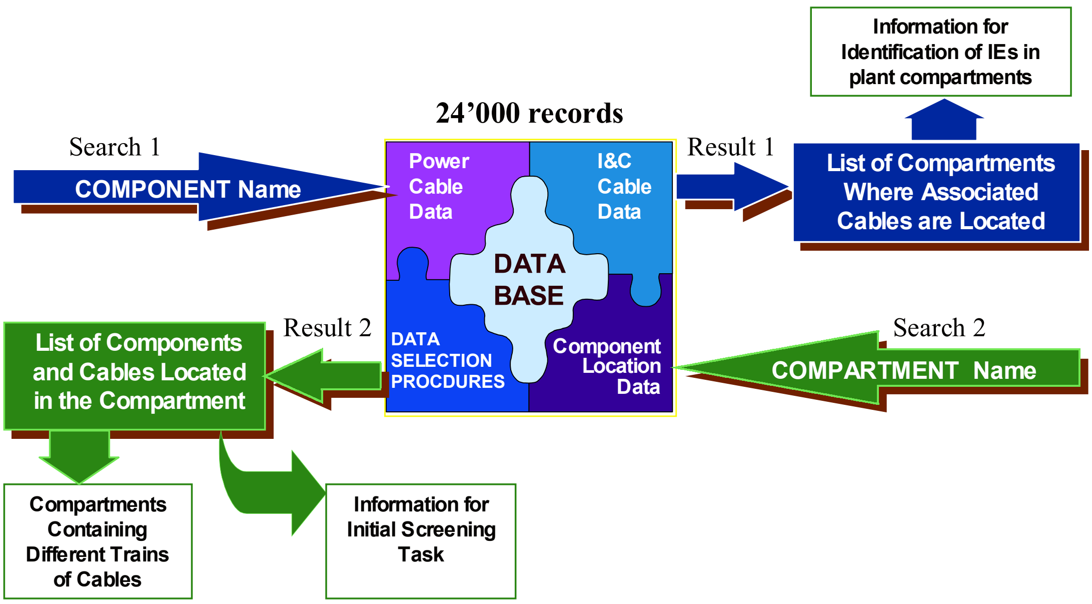

Figure 1. Cable Location Data Base Characteristics

frequency of 1.3E-02 per reactor*year). However, for the two control rooms (i.e., main and reserve) a different approach was employed. The fire frequencies were developed using an area-based approach and partitioned among the control panels (the mean fire frequency for the two compartments was estimated as 3.5E-02 per reactor*year).

The fire initiation frequency for each fire zone was calculated by adding the individual fire frequencies attributed to the components present within the fire zone and a portion of the frequency of transient combustibles and metal works.

Table 1 Generic and Plant-Specific Initial Data and Fire Frequency Estimations for Components-Ignition Sources

Component	Generic Data				Plant-Specific Data				Number of Components in NVNPP-5	Total Fire Frequency for NVNPP-5 per year
	Initial Data		Mean	EF	Initial Data		Mean	EF		
	N of fires	Expos. time			N of fires	Expos. time				
Turbine/ generator	2	2.9E+2	6.9E-3	2.6	0	3.8E+1	6.2E-3	2.6	2	1.2E-2
Diesel-generator	1	3.1E+2	3.2E-3	3.5	0	5.7E+1	2.8E-3	3.5	3	8.5E-3
Pump - electric motor 6 kV	3	5.4E+3	5.6E-4	2.3	1	1.3E+3	6.0E-4	2.1	66	3.9E-2
Pump - electric motor 0.4 kV	1	2.0E+4	4.9E-5	3.5	0	4.8E+3	4.2E-5	3.5	252	1.0E-2
Turbine-driven pump	1	5.2E+1	1.9E-2	3.5	0	3.8E+1	1.2E-2	3.5	2	2.5E-2
Power cable segment	1	7.2E+5	1.4E-6	3.5	0	1.6E+5	1.2E-6	3.5	8200	9.8E-3
I&C cable segment	1	3.3E+6	3.0E-7	3.5	0	7.2E+5	2.6E-7	3.5	37800	9.8E-3
Panel device	1	1.4E+5	7.1E-6	3.5	0	3.6E+4	5.9E-6	3.5	1900	1.1E-2
Transformer >6 kV	3	3.9E+2	7.6E-3	2.3	1	9.5E+1	8.1E-3	2.1	5	4.1E-2
Transformer <= 6 kV	2	9.6E+3	2.1E-4	2.6	1	1.6E+3	2.6E-4	2.3	85	2.2E-2
Switch 6 kV	2	7.3E+3	2.7E-4	2.6	0	2.6E+3	2.1E-4	2.6	139	2.9E-2
Switch 0.4 kV	7	1.1E+4	6.3E-4	1.8	1	1.4E+3	6.3E-4	1.7	76	4.8E-2
Fan	0	1.3E+4	3.8E-5	12.3	0	3.0E+3	1.8E-5	12.3	157	2.9E-3
Inverter	0	7.1E+2	7.1E-4	12.3	1	1.1E+2	4.1E-3	3.7	6	2.5E-2
MOV	0	1.0E+5	4.9E-6	12.3	0	2.4E+4	2.3E-6	12.3	1272	3.0E-3
TOTAL for All Components-Ignition Sources:										3.0E-1

2.7 Human Error Probability Analysis

Human error probabilities (HEPs) used in the internal events PSA were revised taking into account additional conditions caused by a fire that could impact operator actions (e.g., presence of smoke, higher stress levels, fire-induced faulty alarming, information loss). The decision tree approach used in the internal events PSA allowed modeling of the influence of fire effects on operator performance through a modification of performance shaping factors.

For those fire zones where fire or hot gases were present, if an operator action had to take place in that fire zone, it was assumed that the corresponding HEP=1.

For the screening analysis, it was assumed that instrumentation (information) cables are present in the affected zones. This implies that the conditions for operator actions become worse than what was postulated in the internal events analysis. For all operator actions performed from the Main Control Room, the influence factors that model “Scenario Effect”, “Cognitive Complexity”, and “Man Machine Interface" (MMI) were assumed to be worse by one level. If for an HEP, all the influence factors were already at their worst level, the human error was assumed to be a certainty (i.e., HEP=1). An example of HEPs obtained using this approach is provided in Table 2. For comparison purposes, the original HEPs from the internal events PSA are also provided in this table.

Table 2 HEPs from Internal Events PSA and in Case of Fire

Description of Human Interaction	Equipment Failures and Specific Conditions when Performing HI	Identifier of HI in IRRAS Model	Mean		EF [1]
			Internal Event	Fire PSA	
Operator organizes emergency cooldown of primary circuit through secondary circuit, removing steam through SDS-As at a cooldown rate of less than 30 C per hour		HE-EHRSA-SLOCA	4.6E-4	1.0E-2	18.0
		HE-EHRSA-TRANS	9.2E-5	5.6E-3	18.0
Operator opens FAIVs	After closure of FAIVs due to operator failure or fast pressure decrease in SGs following initiating events with steam line breaks, failures of TG stop valves or SDS units to reclose	HE-FAIV0P-LOOP24	4.4E-1	1	7.1
		HE-FAIV0P-SLOCA	2.2E-2	2.4E-1	7.1
		HE-FAIV0P-TRANS	4.4E-3	1.3E-1	7.1
Operator closes valves to isolate SGs from feedwater and emergency feedwater supply	Secondary side unisolable leak from SGs (in case of steam/feed water line breaks or failures to close of SG SVs or SDS units)	HE-FWIV-TRANS	3.1E-4	6.8E-3	4.7
Operator reconnects HPECCS pumps to B-8 tanks	At LOCA events	HE-HPAB8T-SLOCA	7.4E-3	8.1E-2	8.4
Operator starts HPECCS pumps	In case of failure to reclose EGRS or pressurizer safety valves	HE-HPABST-LOOP24	1.8E-3	4.4E-2	8.4
		HE-HPABST-TRANS	1.8E-3	4.4E-2	8.4
Operator actuates HPECCS pumps to provide boron injection	In case of failure of make-up pumps	HE-HPBST-LOOP24	3.1E-4	6.8E-3	8.4
		HE-HPBST-TRANS	3.1E-4	6.8E-3	8.4
Operator stops make-up injection	In case of FAIVs closer	HE-INJOFF-LOOP24	1.8E-2	1.6E-1	4.7
		HE-INJOFF-TRANS	1.8E-2	1.6E-1	4.7
Operator achieves heat removal - make-up from LPECCS	Failures to reclose previously opened emergency gas removal lines	HE-LPECBC-LOOP24	1.4E-2	1.2E-1	18.0
		HE-LPECBC-SLOCA	1.4E-2	1.2E-1	18.0
Operator organized normal cooldown of primary circuit through secondary circuit, removing steam through SDS-C at a cooldown rate of less than 30 C per hour		HE-NHRSK-SLOCA	9.2E-4	2.0E-2	18.0
		HE-NHRSK-TRANS	9.2E-4	2.0E-2	18.0

(1) Error factor refers everywhere the lower bound (defined as Mean/EF), but the upper bound is equal to MIN(1, EF).

More severe conditions were postulated for the dependent operator action than the first action in case of fire (also assessed with the Decision Tree approach [2]). For example, the influence factor “Workload” for a number of dependent operator actions that in internal events PSA was postulated to be “low” became “high” to account for the effects of the fire.

In the detailed analysis of important fire scenarios, a more refined human reliability analysis was performed than in the screening analysis. For each specific case, the reasons for degradation of performance shaping factors were analyzed taking into account the specific instrumentation (information) cables present in the area that could be affected during the fire scenario.

2.8 Multi-Compartment Fire Analysis

The initial screening of fire zones based on the assumption that fires would be confined to the zone itself was not employed in this analysis. The analysis began by postulating a severe fire in each fire zone. All possible propagation paths and mechanisms (i.e., radiative heat, hot gases, and smoke) were considered and documented. A number of assumptions were made for fire effects propagation, and a computer program was developed to automate the multi-compartment fire analysis (i.e. the search for combinations of compartments where the effects of a fire would propagate). The following criteria for fire affects propagation were adopted:

Type of Opening	Propagation Possibility
Door - hermetic	No fire propagation
Door - non-hermetic, unlocked, opens away from the compartment	Hot gases and smoke propagate
Door - non-hermetic, unlocked, opens into the compartment	Smoke propagates
Door - non-hermetic, locked	Smoke propagates
Opening - large (D>150 mm)	Hot gases and smoke propagate
Opening - small (D<150 mm), located higher than 1/2 compartment height	Hot gases and smoke propagate
Opening - small (D<150 mm), located lower than 1/2 compartment height	Smoke propagates

As a result of multi-compartment fire analysis, the following major information pieces were obtained:

- List of individual fire zones and compartments included in each fire zone;
- List of adjacent fire zones tabulated by the fire zone where fire originates (exposing fire zone) and the type of connections to each adjacent fire zone;
- List of components (including cables) within each combination of fire zones.

2.9 Screening Analysis

The goal of screening analysis was to screen out fire scenarios that, using conservative methods and assumptions, could be shown as risk insignificant. The conservatism was provided by taking into account the entire fire propagation zone instead of single fire zones. All equipment/cables within the fire propagation zone susceptible to damage from a fire were assumed failed. The following assumptions were used in the analysis:

- Multiple hot shorts were assumed to be possible. Failure of all control cables in the fire zones affected by each fire propagation scenario was assumed to lead to the worst failure mode in the affected control circuits. It was typically assumed that:
  - the standby equipment change its state (e.g., valves that should remain open are closed, and vise versa),
  - normally operating equipment (e.g., pump, regulating valve, and fans) stop operating, and

- after a spurious actuation, it is assumed that the affected equipment would be rendered inoperable.

- An equipment item is assumed to be rendered inoperable, if its power cable is within the fire propagation zone.

The internal events PSA model modified to include the specific conditions by the fire was used for screening calculations. The core damage frequency (CDF) associated with each fire scenario was estimated and those scenarios with a CDF less than 5.0E-07 per reactor*year were screened out.

As a result of the screening process, three categories of fire propagation scenarios were identified:

1) Fire scenarios with CCDP less than 5.0E-6

   The scenarios with this CCDP were screened out based on impact. Initiating events assigned to these scenarios were “Administrative Shutdown”. The CDF for this group of fire scenarios (assessed conservatively) was less than 1.9E-06 per reactor*year, which is less than 0,3 percent of the total CDF from internal events.

2) Fire scenarios with CCDP higher than 5.0E-6

   For the scenarios that could not be screened out by impact (i.e., CCDP higher than 5.0E-06), the CDF of the scenarios was evaluated using the SAPHIRE/IRRAS computer code. It should be noted that since the total CDF of the screened out scenarios obtained using the assumption that all possible spurious actuations have occurred were deemed to be unrealistically too large, all the scenarios that screened out were reviewed for inclusion of the probability of spurious actuations due to hot shorts based on the approach presented in Reference [4]. The total CDF for scenarios from this group that were screened out is 6.9E-6 per reactor*year. The remaining scenarios were subjected to detailed analysis.

3) Fire scenarios with CCDP equal to 1

   For a group of fire scenarios, CCDP=1 was assigned from direct inspection of the equipment affected. The CDFs were not estimated for these scenarios since they would be equal to the fire frequency.

   The resulting list of fire zones, which were subjected to detailed analysis, was developed. For each particular case, this table provides the reasons for a fire scenario being dominating and possible ways of reducing the conservatism in assessing the CDFs.

2.10 Control Room and Cable Spreading Room Analysis

The control rooms and cable spreading rooms are areas where the potential for an impact on redundant safety system trains exists. The goal of control room analysis was to identify scenarios that begin with the initiation of a fire in a control panel or transient fuel fire outside the panels, and lead to core damage by causing spurious actuation of equipment, equipment unavailability due to loss of control, and by directly or indirectly affecting human actions.

A comprehensive control circuit analysis was performed as a part of control room and cable spreading room fire analysis The control circuits of specific equipment were analyzed to verify the possibility of spurious actuation from damage to the associated control cables. The possibility to eliminate the spurious signal from other control areas was verified for each particular case and credited as recovery actions. For cable spreading rooms, the analysis focused on identification of scenarios involving fire in multiple cable trays, which would lead to failure of a critical set of PSA components.

2.11 Detailed Analysis

The objective of detailed analysis step was to reduce the level of conservatism in those postulated fire scenarios that were not screened out in the screening step, and to obtain a realistic estimation of the fire risk.

A series of calculations was performed by COMPBRN-IIIe [6] and MELCOR [7] computer codes in order to establish more realistic scenarios than what had conservatively been assumed in the preceding steps. COMPBRN was used for modeling single compartment fire propagation scenarios. MELCOR was used to model multi-compartment fires. Fire phenomena were modeled to assess the impacts of specific fires (e.g., fuel type, shape and location) in a fire zone and draw conclusions regarding the possibility of damage to equipment of interest located in those zones. The results were used to establish the possibility of specific fire scenarios, which start from the ignition of specific combustibles leading to damage to a critical set of cables and/or objects. The critical set was defined in terms of sets of objects that if failed, could lead to a degradation of core cooling capability. The results of the fire propagation analysis also provided a measure of the severity of fires in terms of the type and quantity of the combustibles where would fire initiate (pilot fire), and the time required to critical damage. This information was used to establish the conditional probability of occurrence of such a fire scenario given that fire had occurred in that fire zone.

In order to model the fire scenario in a realistic way, several additional walkdowns were performed to verify and collect specific information about the design features and geometry of compartments, equipment characteristics, barriers and connections among compartments, etc. Possibility of fire detection and suppression was also credited in a few cases where damage to critical cables and equipment would potentially be minimized by such systems.

2.12 Risk Contributor Identification and Report Preparation

All fire scenarios were quantified using the internal event PSA model and contributors to the CDF were obtained. Uncertainty parameters were assessed. For most significant fire scenarios and assumptions employed in the study, sensitivity analyses were performed. Final conclusions regarding the fire-related risk profile were drawn. The entire fire risk analysis was documented in the form of a Final Report and a set of supporting Appendices.

3 RESULTS

The total CDF point estimation from internal fires assessed for this plant was found to be 5.6E-04 per reactor*year. For this frequency, the contribution of screened-out scenarios is 8.8E-06, which is less than 1.5 percent from the total CDF. The total CDF from internal fires assessed for NVNPP-5 is comparable to the CDF from internal initiators (6.9E-04). Preliminary quantitative results obtained in the framework of the fire PSA grouped by major plant areas are provided in Table 3. A brief description of reasons for the contribution to the CDF is discussed in this table. For the sake of convenience purposes, Figure 2 presents the diagram of contributors to the CDF.

Table 3 Preliminary Quantitative Results

Plant Areas	Fire Occurrence Frequency	CDF	% CDF	Comments
Main Control Room and Relay Cabinets	3.5E-2	1.4E-4	25.1	The CDF is mainly driven by: • The fires in specific panels. For the Main Control Room, one of the important contributors is safety system panels. The three safety panels in the MCR are not separated by side walls. COMPBRN calculations show that multiple panel damage would occur in 3 minutes. For the Relay Cabinet, a number of significant fire scenarios were also identified. The control relay boxes in Relay Cabinets are arranged in rows with no partitions in-between. Multiple equipment damage is assumed. Note: No credit was given to fire suppression in these control areas. • Failure of some of the control circuits that may lead to spurious actuations and loss of equipment control.
Cable Shafts	1.2E-2	1.2E-4	21.5	For several cable shafts, it was identified that a number of important cables are located in the same shaft. Spurious actuation of equipment because of control cable failure is an important part of these scenarios. Note: No credit was given to the possibility of timely fire suppression.
Turbine Hall	6.2E-2	1.2E-4	21.5	The CDF is driven by a number of fire scenarios involving oil and hydrogen fires. Part of the contribution is driven by severe fires resulting in roof collapse.
Deaerator Compartment	2.8E-3	4.9E-5	8.8	The contribution is driven by fire scenarios resulting in damage to a single cable tray. Spurious actuation of equipment because of control cables failure is an important part of these scenarios. This phenomenon led to high CDF. Note: Fire suppression was not credited in the analyses.
Switchgear Compartments	1.0E-1	4.5E-5	8.1	The contribution is driven by relatively high fire frequency. Some credit was given to the possibility of manual fire suppression.
Cable Spreading Rooms	6.3E-3	2.6E-5	4.6	The contribution is driven by fire scenarios involving damage of several cable trays. Note: due to incompleteness of information on exact location of cables in trays, conservative scenarios had to be postulated for a number of cases. Note: Some credit was given to automatic fire suppression.
Boron Building Compartments	4.1E-3	1.8E-5	3.2	The contribution is mainly due to the fire scenario involving the transportation corridor, where a number of safety important equipment cables is located. Spurious actuation of equipment because of control cable failure is an important part of these scenarios. Note: No credit was given to fire suppression.
Containment	8.2E-3	8.6E-6	1.5	The contribution is due to Main Coolant Pump oil fire.
Transformer Yard	4.1E-2	7.1E-6	1.3	The contribution is due to explosions in yard transformers that lead to a fire that propagates into the turbine hall.
Compartments Below the Containment	8.2E-3	6.9E-6	1.2	In this area, the oil system of the Main Coolant Pumps is located. MELCOR analyses showed that in spite of significant connections among the compartments, the damage to important equipment does not occur.
Auxiliary Building Compartments	5.8E-3	6.2E-6	1.1	The oil system of the Make-up Pumps is the main fire source of concern for these compartments. MELCOR analyses showed that in spite of significant connections between compartments, the damage to important equipment does not occur.
Hermetic Penetration Compartments	2.1E-4	2.5E-6	0.4	
Service Water Building	1.5E-2	2.3E-8	0.0	
TOTAL FROM THE DETAILED ANALYSIS	**3.0E-1**	**5.5E-4**	**98.5**	
Screened out by CDF		6.9E-6	1.2	
Screened out by Impact		1.9E-6	0.3	
TOTAL FROM SCREENED SCENARIOS		**8.8E-6**	**1.5**	
TOTAL CDF		**5.6E-4**	**100**	

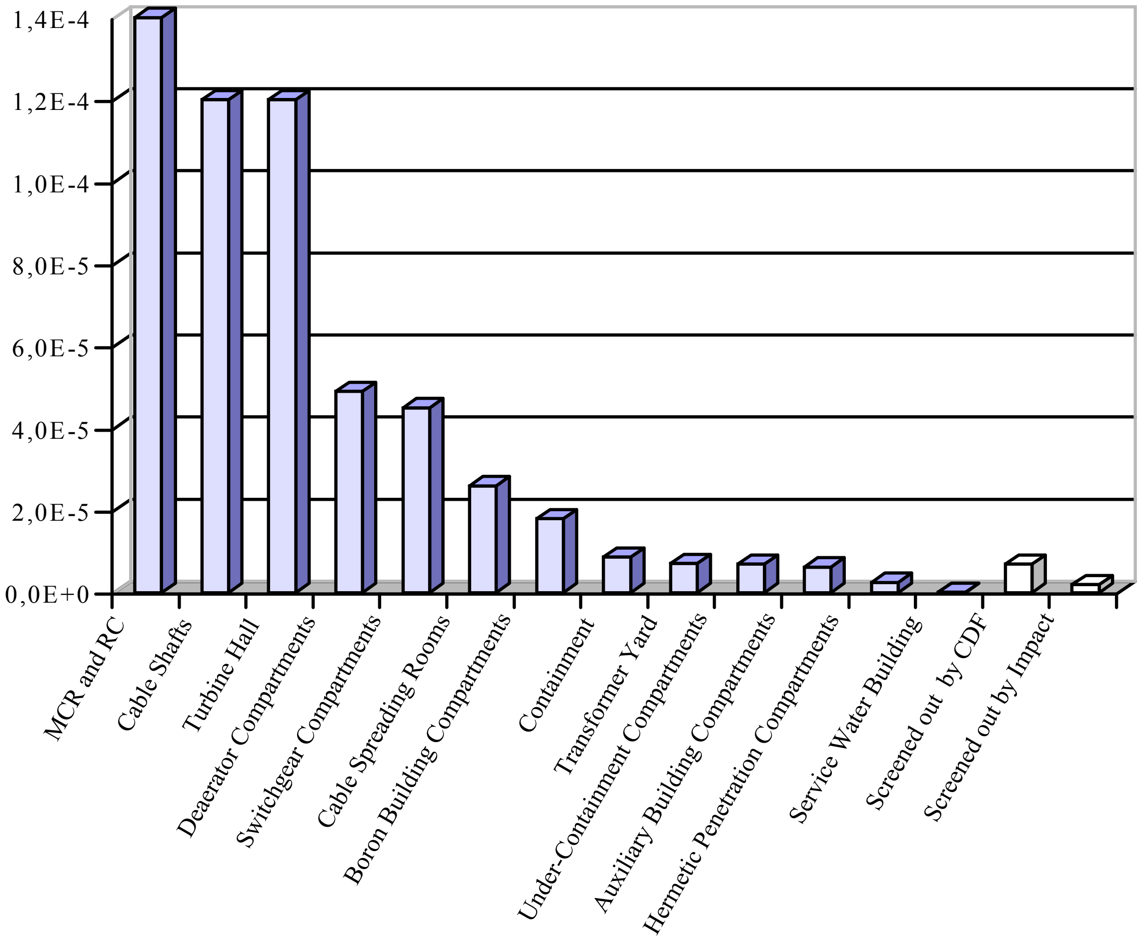

Figure 2 Contributors to the CDF due to Fires

4 CONCLUSIONS

A full-scope fire PSA was conducted for the Unit 5 of Novovoronezh NPP. From the review of the preliminary results it can be seen that the contribution to core damage frequency from internal fires is comparable to the contribution from internal initiators.

No fire scenarios could be identified that may directly lead to core damage without any possibility of recovery actions to avert such catastrophe. For all fire scenarios, for the minimum, manual actions could be find that the operators could take within a reasonable time to restore lost core cooling functions. A few fire scenarios were postulated that could render all core cooling functions inoperable for an extended time. These scenarios, however, were concluded to be practically impossible based on the quantity of combustible materials needed to inflict such damage or the barriers that had to be overcome by the effects of a fire.

Areas of the plant with high concentration of control circuits were found to be the most important contributor to core damage. The control room, relay cabinets, cable shafts and the cable spreading room were found to be the most important fire risk contributors. For these areas spurious actuation of equipment because of control circuit failure were found to be a key element of the accident scenarios. Since the mechanisms leading to spurious actuation of equipment is not well understood, much uncertainties exist in the level of contribution of the scenarios including spurious actuations to the overall fire risk. However, given the large concentration of control and instrumentation cables in the control areas of the plant, those areas are important to fire risk regardless of the level of uncertainties.

Absence of separation between safety system panels in the Main Control Room resulted in the possibility of severe damage to multiple safety-related equipment in case of fire. For a part of quantitative results, the contribution is due to relatively high fire occurrence frequencies, which were assessed with usage of a restricted statistics data on fire incidents. Fire in the turbine hall could lead to severe consequences because of large quantities of combustible liquids and important secondary side equipment present in that building.

Sensitivity and uncertainty analyses will be performed for the most uncertain issues, which would allow to asses the significance of scenarios, the contribution of which is driven by relatively high fire occurrence frequencies or conservative assumptions implemented for the analysis. It should be specifically noted that for a number of fire scenarios, the conservative assumptions had to be taken as there was a lack of information on location of cables inside compartments and particular cable trays. One of the insights is that it is important to establish a comprehensive cable location database in order to allow for decreasing the conservatism of the analysis and efficiently organize the cable inventory management.

The results of this fire PSA study may be considered by plant management and taken into account in plant modification programs.

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